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ADVANCED TECHNOLOGY CENTER, INC.

INVESTIGATION OF SUBSTRATE-MOUNTED THIN-FILM METEOROID SENSORS FOR USE IN LARGE-AREA IMPACT EXPERIMENTS

Modification 3S, Contract NAS 9-12009

ATC Report No. B-94500/3CR-7

26 February 1973

The Research Center of LTV Aerospace Corporation and LTV Electrosystems, Inc.

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1.0 Introduction and Summary

The study described here is an experimental investigation of the feasibility of fabricating large-area thin-film capacitors onto thick substrates of aluminum for application as meteoroid impact sensors. Self-supporting thin-film sensors having an area of approximately 1 in^2 were previously developed by the LTV Research Center (predecessor of the Advanced Technology Center) for use as sub-elements in meteoroid detector rays. These sensors detected impacts and measured velocities of micron-range particles in the velocity range above approximately 4 km/sec. Detector arrays comprised of this type of sensor element were used on the NASA RMS and MTS satellite meteoroid experiments, supplied by the Advanced Technology Center. These satellites, under Contracts NAS9-11446 and NAS9-9195, were placed in near-earth orbits in November 1970 and August 1972, respectively. The principal objective of the present study was to advance the state of development of such meteoroid detectors to allow a significant increase in the area of single detector elements. As the use of such sensors solely for meteoroid impact detection does not require that the elements be self-supporting, larger areas can be attained by applying or preparing the thin-film sensor specimens onto relatively thick substrates. The substrate material could thus be the surface of a spacecraft structural member of other large-area surface.

In the present study two types of sensor designs were investigated: (1) A polysulfone dielectric film with vapor-deposited aluminum and gold sensor plates, bonded to a relatively thick aluminum substrate, and (2) an aluminum oxide (Al_2O_3) dielectric layer prepared on an aluminum substrate by anodization, with a layer of vapor-deposited aluminum providing one sensor plate and the substrate serving as the other plate.

In the first design, specimens were prepared which indicate the state of the art for application of this type of sensor for elements of a meteoroid detection system having an area as large as 10 M^2.

Techniques were investigated for casting large-area polysulfone films on the surface of water and for transferring the films from the water. Methods of preparing sensors by layering of films, the deposition of capacitor plates, and sensor film-to-substrate bonding, as well as techniques for making electrical connections to the capacitor plates, were also studied. Sensor specimens of this type, having an active area of 34.2 in^2, and 8.4 in^2, were delivered to NASA-Langley Research Center for evaluation.

Experimental specimens of the second type of detector (Al_2O_3) were fabricated on aluminum substrates of varying degrees of purity and various thicknesses. Of this type, specimens having areas ranging from 1 in^2 to 36 in^2 were delivered to NASA-LRC.

Simulated meteoroid impact tests were performed by NASA on both types of capacitor sensors. These tests were carried out by NASA-LRC and Goddard Space Flight Center personnel in the meteoroid facility at the NASA-Goddard Space Flight Center. The results of these tests and electrical tests performed at ATC indicate that the Al_2O_3 capacitor with relatively thick substrates would be an extremely efficient, reliable, and very lightweight sensor for large-area, long-term space meteoroid probes.

2.0 Sensor Design and Fabrication

A description of the design and fabrication of the sensors delivered to NASA in this study follows in this section.

2.1 Polysulfone Dielectric

This type of sensor differs in design from those employed on the MTS and RMS satellites in the amount of active sensor area, and in the method of sensor mounting and support. As shown schematically in Figure 1, the sensor element is comprised of a 700Å layer of aluminum, a 6-layer dielectric of polysulfone, and a 500Å layer of gold, mounted on a thick aluminum substrate. The polysulfone layers were cast on the surface of water and transferred from the water by means of rings designed and fabricated for this process. The first layer of dielectric placed against the aluminum substrate is coated with a 500Å layer of gold, which forms the back plate of the sensor. Various methods of making electrical connections to the sensor plates were studied. The most effective of these is to coat the edge of the gold layer with a silver conductive layer, E-Kote #3030[1]. This coating provides assurance of a conductive contact in addition to the intimate contact that the gold coating makes with the aluminum substrate. Four layers of polysulfone comprise the heart of the dielectric, the layers being lifted one at a time from the water surface by means of the above-mentioned lifting rings. A sixth layer of dielectric material has a vapor-deposited 700Å aluminum coating which forms the front plate of the sensor. A coating of E-Kote #3030 applied to an insulated tape, Scotch #62[2], provides a bridge from the evaporated Al plate to the aluminum substrate, thus forming the other connection. The total dielectric thickness is nominally 6000Å, with a capacitance per unit area of 0.029 $\mu f/in^2$. An example of this type sensor specimen is shown in Figure 2. This particular specimen was

[1] Epoxy Products, Inc.

[2] 3M Company

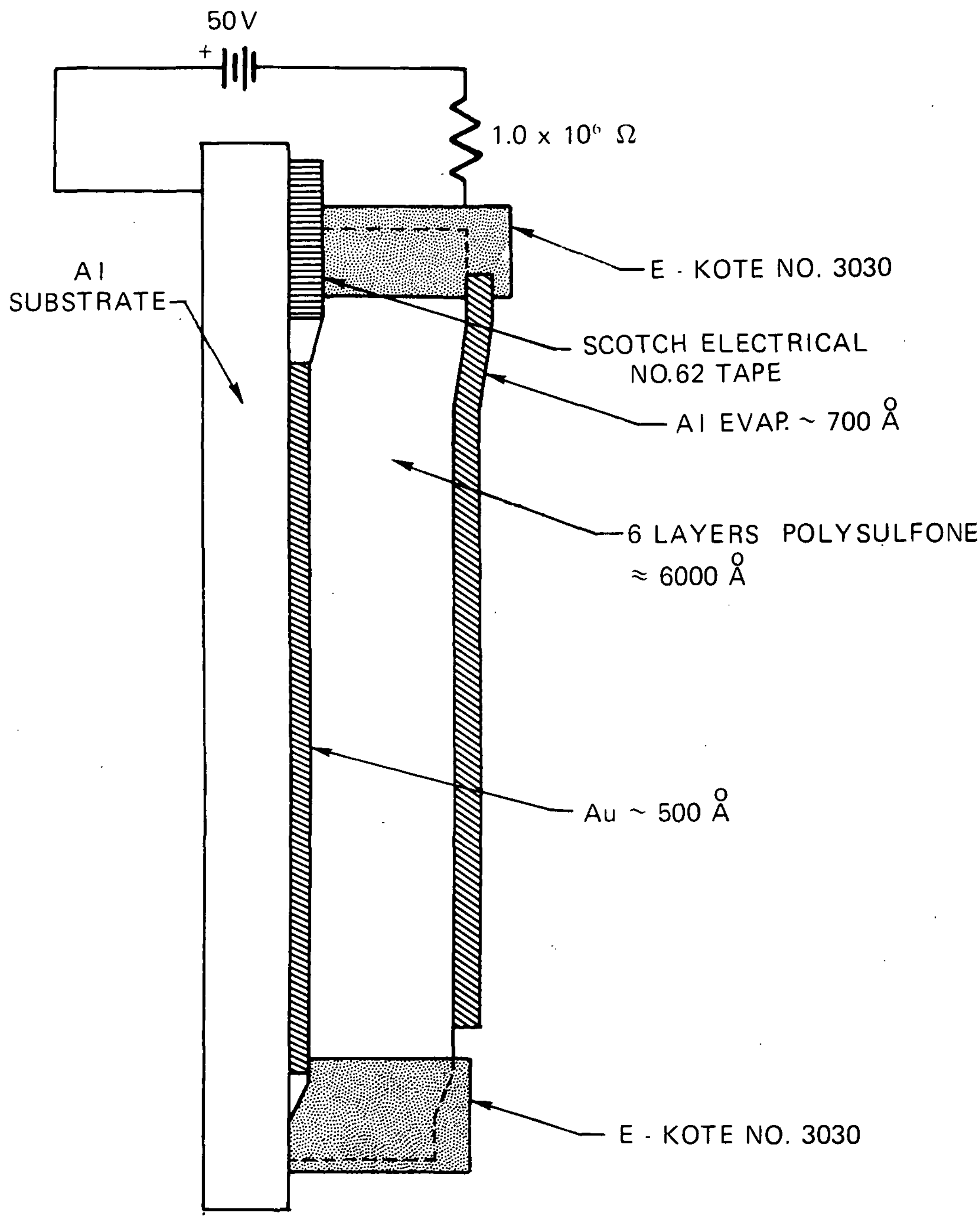

FIGURE 1 - Schematic of a Polysulfone-Dielectric Micrometeoroid Sensor

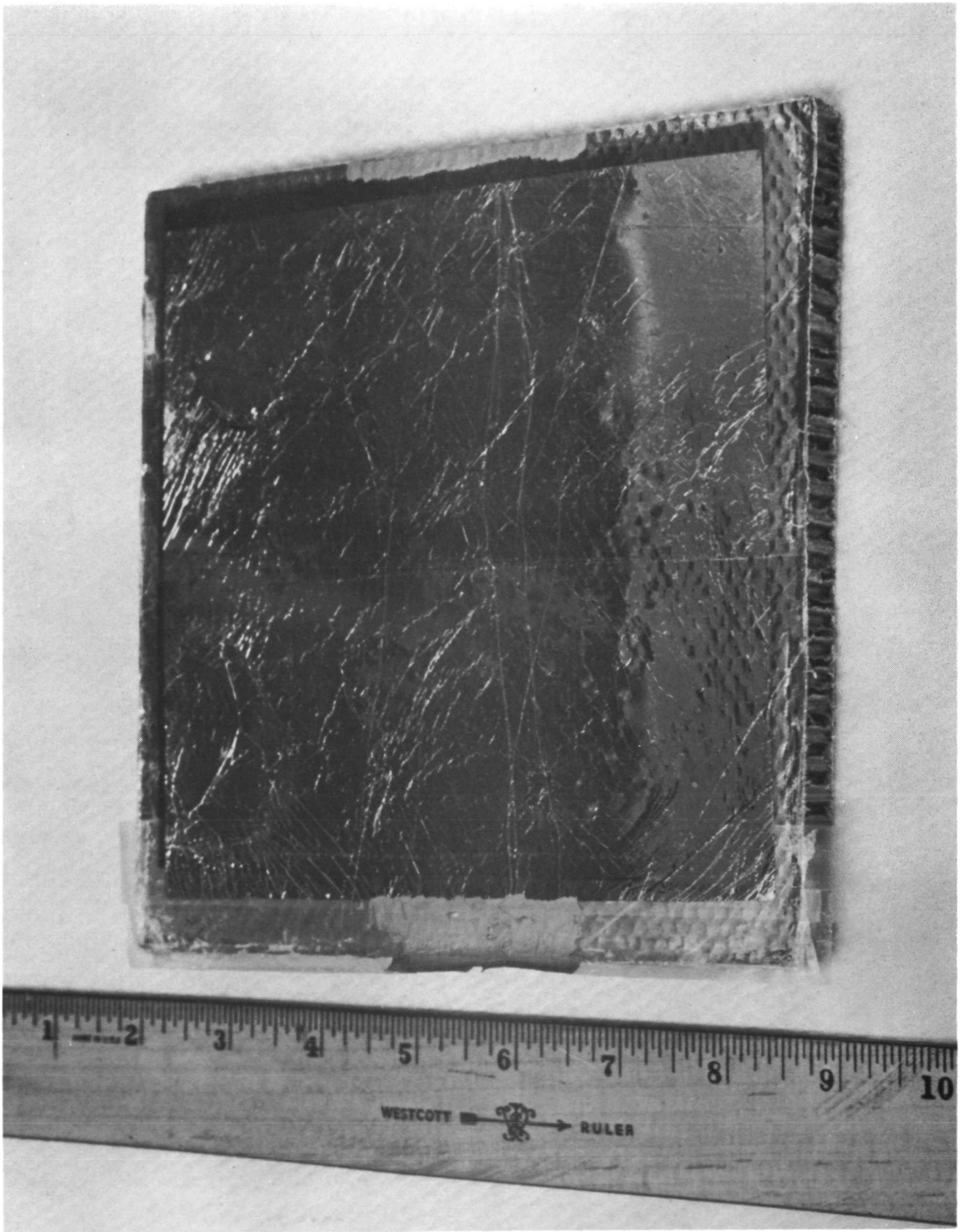

FIGURE 2 - Polysulfone-Dielectric Micrometeoroid Sensor on an Aluminum Honeycomb Substrate

mounted in intimate contact with the thin aluminum skin of a honeycomb structure, such that the sensor film exhibits a high degree of conformity to the skin surface, which is "dimpled" by the underlying honeycomb.

2.2 Aluminum Oxide Dielectric

In an earlier study (Contract NAS9-5976) by ATC a type of meteoroid sensor was demonstrated which consisted of a self-supporting dielectric film of aluminum oxide (Al_2O_3), with aluminum plates. In the present study an investigation was made of the feasibility of applying this type of sensor to large-area substrates, as this design offers increased sensor ruggedness and greater electrical stability. The design employing this type of construction is shown schematically in Figure 3. This type of sensor, which uses an anodization process to form the dielectric on a substrate, has an additional advantage that sensors may be conveniently applied to both sides of a substrate. Various forms of high-purity aluminum substrate such as plates, foils, and tapes lend themselves to the Al_2O_3 sensors. This material selected as substrate is pre-etched to remove surface contamination and blemishes. It is then suspended in an anodizing solution and a bias applied, using a voltage-limited, constant-current power supply. The oxide layer builds until the supply voltage limits, and the current drops below a predetermined lower limit. The thickness of the resulting dielectric film is a function of the limit voltage. Setting of the anodizing current depends on the sensor substrate surface area and the choice of optimum anodization time. Poor quality dielectrics result from too rapid an anodization time. The anodized substrate is masked to the desired plate geometry and vapor coated with the aluminum layer, which is the other plate of the sensor. E-Kote #3030 applied to the evaporated aluminum coating forms the electrical connection to this sensor plate. Electrical testing of these specimen indicated that they are extremely reliable. Bias voltage for normal operation is 40 volts. The capacitance per unit area for a nominal dielectric thickness of 5000Å is 0.08 $\mu f/in^2$. $Al-Al_2O_3-Al$ sensor specimens with active areas ranging from 1 in^2 to 36 in^2 were fabricated in the present study. An example of a

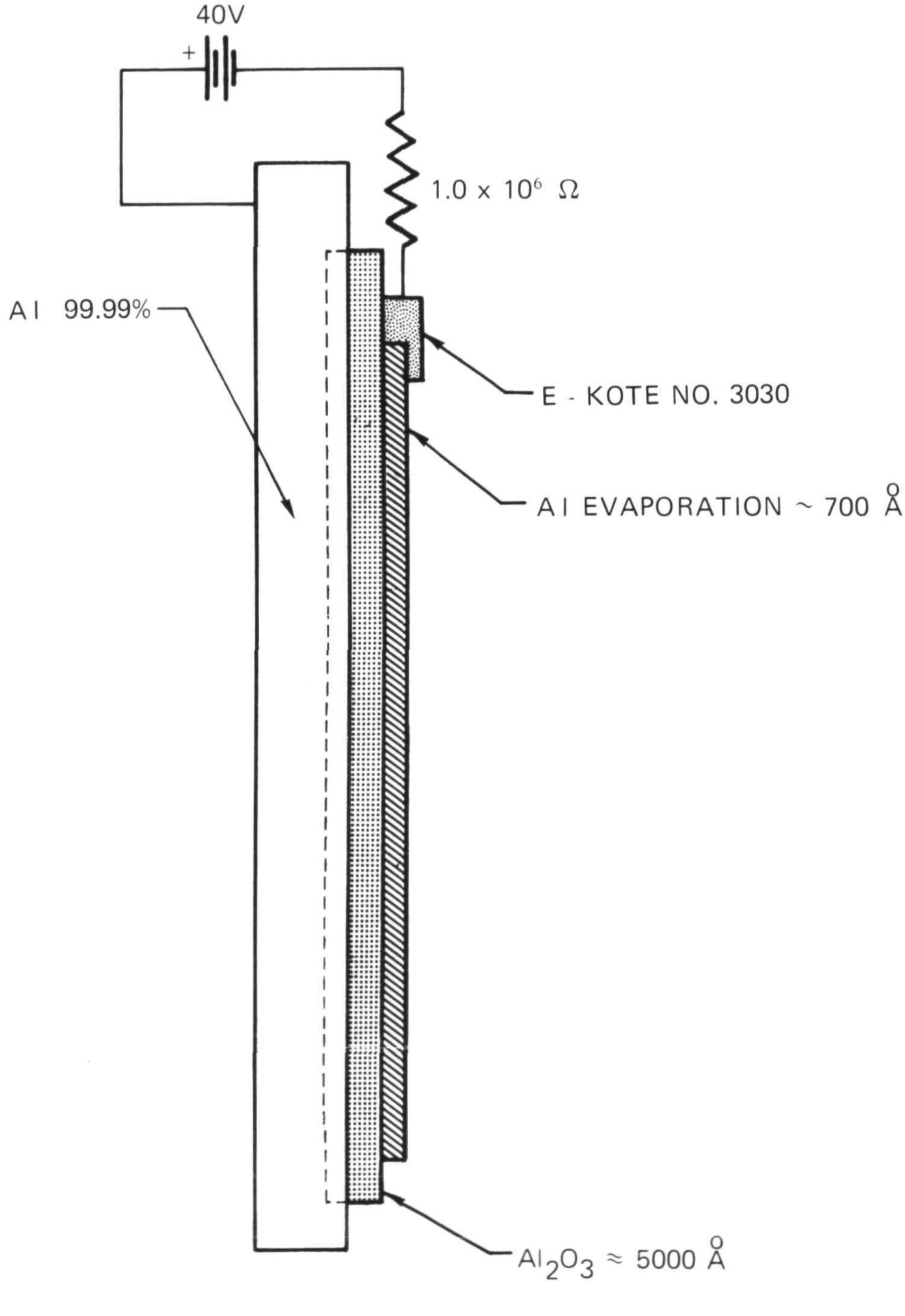

FIGURE 3 - Schematic of an Aluminum Oxide Large-Area Micrometeoroid Sensor

36-in^2 specimen is shown in Figure 4, and additional specimens of various sizes are shown in Figure 5 and 6. Figure 6 shows a sensor formed by anodization and coating of an adhesive-backed aluminum tape as substrate. This specimen was prepared to evaluate the effect of flexing of sensors mounted on thin substrates. This type of flexible substrate with adhesive backing has obvious potential applications in the mounting of sensors in intimate contact with curved or irregular surfaces.

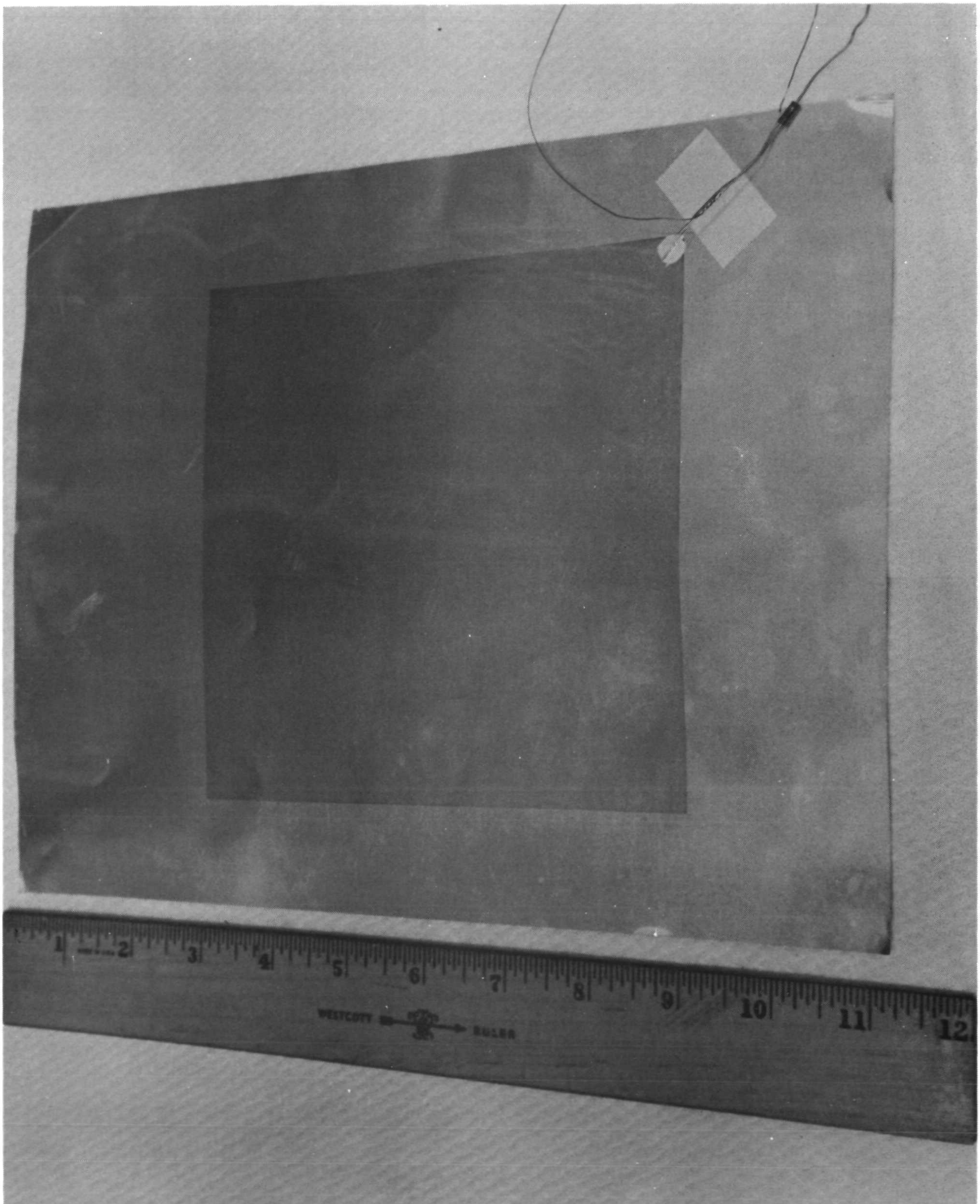

FIGURE 4 - Aluminum Oxide Dielectric Micrometeoroid Sensor on an Aluminum Substrate

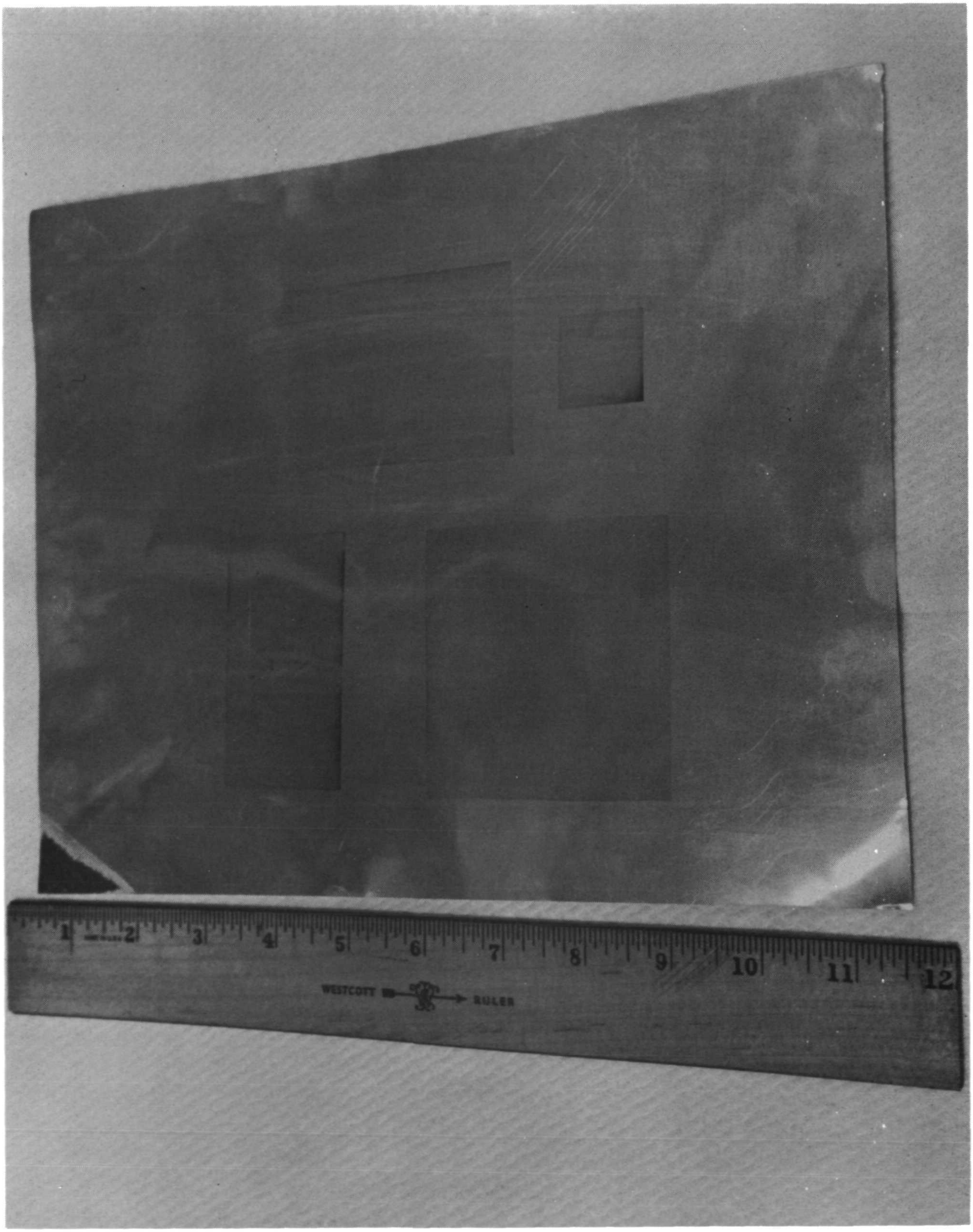

FIGURE 5 - Multiple Aluminum Oxide Dielectric Micrometeoroid Sensors on a Single Aluminum Substrate

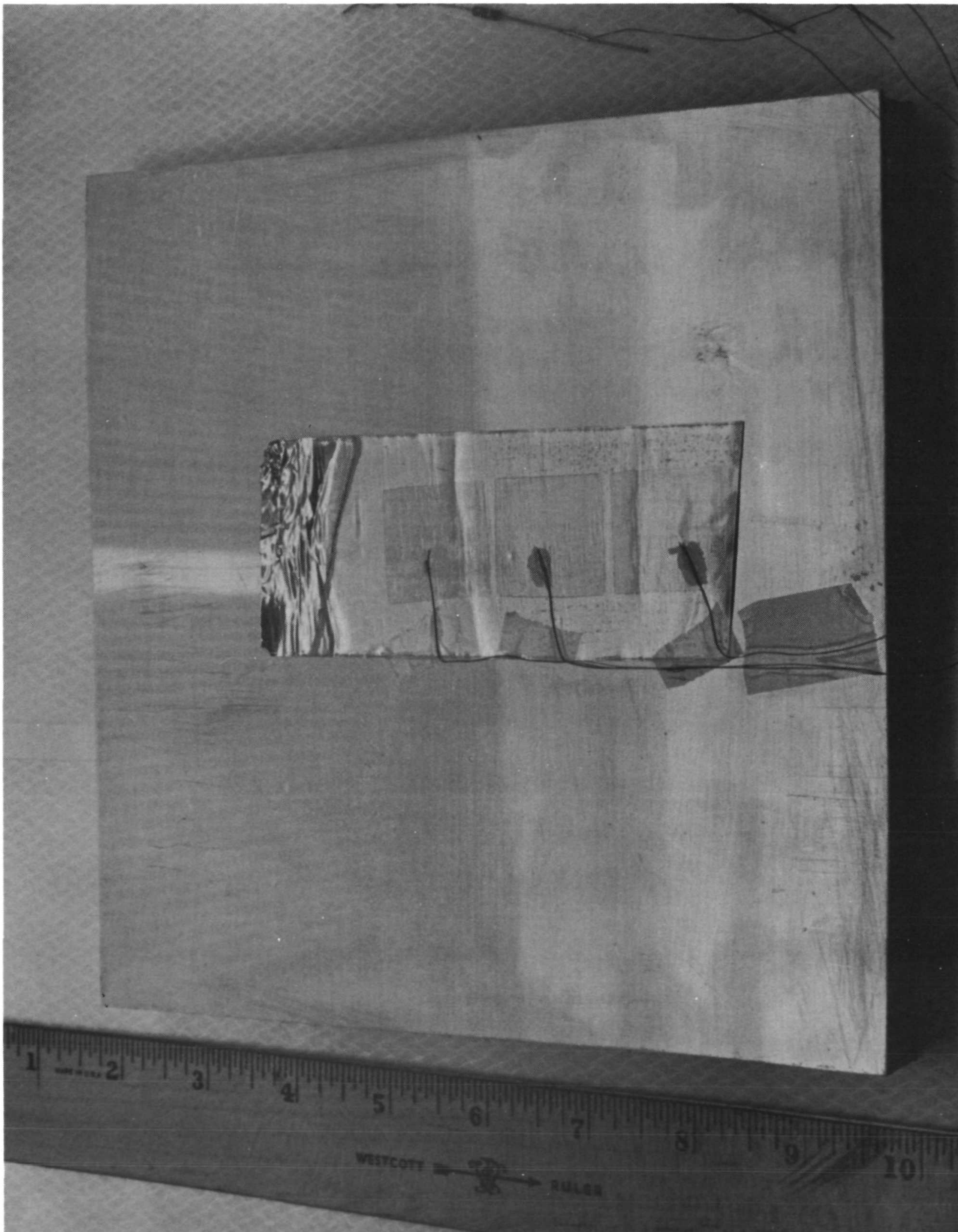

FIGURE 6 - Aluminum Oxide Dielectric Micrometeoroid Sensor on an Adhesive-Backed Aluminum Tape as Substrate

3.0 Testing

Sensor specimens delivered to NASA were subjected to tests for electrical leakage and breakdown and to simulated meteoroid impact tests. Electrical testing was performed in the ATC laboratories, while impact testing was performed at the NASA-Goddard Meteoroid Facility by Langley Research Center and Goddard Space Flight Center personnel.

3.1 Electrical Tests

Current leakage tests were performed with sensors in both air and vacuum. In this test a voltage equal to or exceeding the nominal bias voltage is applied to the sensor plates. The leakage current is monitored for a minimum period of 5 minutes, and sensors with electrical noise or excessive leakage (>1μa) are rejected. To obtain information on the sensor breakdown characteristics, selected sensors were placed under bias for varying lengths of time. Although both types of sensors passed this test, the Al_2O_3 sensors are in general superior in both leakage and breakdown categories. A 16-day bias test on a typical specimen produced no breakdowns. Typical current leakage for the 36 in^2 Al_2O_3 sensors are in the range of 10^{-9} amperes.

3.2 Impact Tests

The NASA-GSFC 2-MeV Van de Graaff meteoroid accelerator supplied the particles used by NASA personnel for impact testing of the sensor specimens.

The results of these tests indicate that the Al_2O_3 large-area sensors are highly efficient, reliable, and well-suited to use as an impact detector. It became apparent during these tests that although the polysulfone sensors have been well-proven as velocity detectors, the large-area specimens as supplied here are less suited for detector of impacts only, due to leakage and spurious breakdown, and frequent shorting after impact. In contrast, the Al_2O_3 sensors detected every particle which was known to have impacted the sensors and produced no breakdowns which were known to be spurious ones. Reducing the bias below 20 volts caused the expected result of reducing the impact signal from the volt range to the millivolt range, since the applied voltage was reduced below avalanche level.

4.0 Conclusions

From this study the Al-Al_2O_3-Al sensor emerges as an excellent candidate for a large-area, extremely lightweight meteoroid impact detector for long-term space probes. This type of sensor,fabricated as described here, is efficient and reliable. For use as an impact detector, where particle velocity degradation is not a critical design factor, these sensors are superior to the thin self-supporting films used in the velocity experiments of RMS and MTS, as they are extremely rugged in comparison. A noteworthy feature of this type of sensor is that it can be added to a relatively flat surface without adding appreciable weight or volume to the structure. The back side of a large dish antenna is considered as the most likely surface of a spacecraft to provide a large area for applying meteoroid impact sensors such as these. Another interesting possibility in this respect would be to anodize suitable portions of the spacecraft structure and deposit the other aluminum sensor plate directly on the structure.

It is recommended here that further studies or experiments be carried out using the Al_2O_3 meteoroid sensors. These studies should include:

1. Further studies on techniques for preparing electrical contacts, optimizing dielectric thickness and selecting plate materials.
2. Investigations of fabrication techniques for preparing Al_2O_3 sensors on adhesive-backed aluminum tapes.
3. Experiments investigating anodization of structural surfaces and direct application of sensor plates on the anodized surfaces.
4. Space qualification of the Al_2O_3 sensors through "piggy-back" experiments or through environmental simulation in appropriate laboratories.

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